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NATIONAL ACADEMY OF SCIENCES

Number 11 • May 1958

IGY BULLETIN

A monthly survey by the U. S. National Committee for the International Geophysical Year. Established by and part of the National Academy of Sciences, the Committee is responsible for the U. S. International Geophysical Year program in which several hundred American scientists are participating and many public and private institutions are cooperating.

Blue Glacier Studies

The information on which this report is based was supplied by Phil E. Church, Chairman, Department of Meteorology and Climatology, University of Washington, and Robert P. Sharp, Chairman, Division of Geological Sciences, California Institute of Technology.

Glaciers are among the most sensitive climatic indicators in nature: the snow and ice strata deposited from year to year provide a record of past climates and climatic fluctuations; and annual variations in accumulation and ablation (loss of snow or ice, primarily by melting) and advances and retreats of the ice front constitute keys to past and current climatic trends.

During the IGY, glaciologists and meteorologists of many nations are studying most known ice areas of the world, including both the great ice sheets of Greenland and Antarctica and a large number of valley glaciers from polar to equatorial regions. Ultimately, comparison of data accumulated through these worldwide studies will permit a better understanding of past and present epochal climatic variations. Moreover, implicit in an accurate knowledge of present trends are clues to future climates. The broad aspects of the US-IGY Glaciological Program are outlined in *Bulletin No. 2, August 1957*.

As part of the US-IGY effort to determine the present pattern and magnitude of shrinkage or growth of glaciers in the United States and Alaska, two teams of scientists are studying the Blue Glacier in the Olympic Mountains of Washington (Fig. 1) intensively. The University of Washington has established a permanent field station in the upper (accumulation) area of the glacier, and scientists of the California Institute of Technology are working in the lower (ablation) area of the glacier during the summer.

The University of Washington team is studying the mass budget of the glacier, the balance between the snow and ice accumulated and that lost by melting and erosion. This is primarily a meteorological study. The Caltech group is investigating the three-dimensional geometry of the Blue Glacier, its surface velocity, and the distribution of velocity with depth.

Blue Glacier itself is a small valley glacier

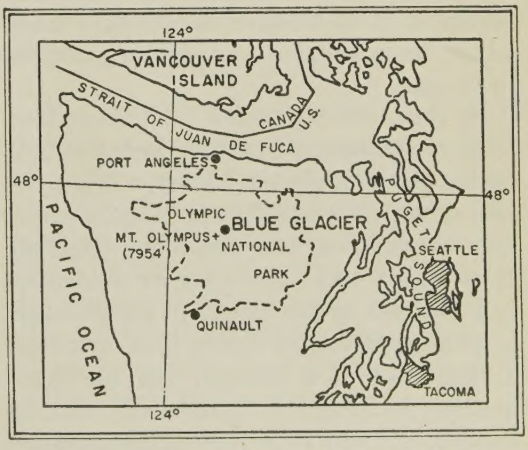

Fig. 1. *Map of Olympic National Park Area, Washington State, Showing Location of Blue Glacier.*

draining from snow fields on the northeast slope of Mount Olympus (47°47′N, 123° 42′W), which lies within the Olympic National Park. It is 2.5 mi long and 0.7 mi in maximum width. Although most of the world's glaciers are retreating at present, Blue Glacier is thought to be growing larger. Most of its accumulation area lies between elevations of about 5900 and 7600 ft above sea level on the 7954-ft mountain.

University of Washington Studies

The University of Washington station is located on a rock outcrop adjacent to the "Snowdome," a domed portion of the accumulation area in the upper part of the glacier, at an elevation of about 6800 ft. This station was established in June 1957. During the next two months a permanent building was erected for use as a headquarters and, nearby, a generator shack, meteorological building, and storage facilities for explosives were also constructed. A "fire cache" was constructed near the camp to hold emergency supplies and equipment to provide shelter in the event of fire or loss through natural disaster. Building materials and supplies were air-dropped by the US Air Force, and scientific equipment was brought in by Air Force and Coast Guard helicopters. The station is also supported by weekly flights of a ski-wheel-equipped light plane which lands supplies and carries personnel in or out.

By the end of September 1957, the meteorological equipment had been installed both on the glacier and at the camp, a triangulation survey to establish a control network for map preparation was virtually completed, 18-ft stakes to measure glacier movement had been set in the cirque (a steep-walled, amphitheatre-shaped recess in a mountain at the head of a glacier), and the headquarters building was completely ready for occupancy. Daily radio contact is maintained with Olympic National Park Headquarters, which cooperated greatly in establishing the station and continues to aid in its operation.

The station was manned by four men from July to September 30, 1957. Beginning on September 1, the winter schedule went into effect: two men remain at the station while the other two work at project headquarters at the University of Washington reducing and analyzing data. The two-man teams alternate each month.

The office work performed at the University of Washington includes reduction of solar radiation data, preparation of a sketch map, and estimate of the 1957 glacier budget. Snow temperature and time profile plots have been worked out for all data collected through the end of December 1957. Some data reduction and survey computations are also done by the field party.

Standard weather observations began in July 1957. The weather data obtained are transmitted daily to Port Angeles by radio. Snow records, obtained daily when weather permits, include amount of snowfall, water equivalent of snow, crystal type, surface densities, and the temperature profile in the surface layers.

Precipitation: Through January 1958, weather records suggest that the wettest part of the continental United States may be on Mount Olympus, near Blue Glacier. It was formerly thought that the Spruce-Quinault area, near the southern border of Olympic National Park, receives the maximum annual precipitation in the United States. However, in the period August through December 1957 there were 61.25 inches of precipitation at Spruce and 45.61 inches at Quinault, while the Blue Glacier Station measured a total of 67.90 inches. Moreover, high winds in November and December may have prevented the rain gauge from recording all the precipitation that fell. The total precipitation through February 1958 was 125.82 inches.

In general, precipitation increased greatly from summer into the fall and winter months—from 5.03 inches in August to 30.44 inches in January. The late fall and winter precipitation fell mostly as snow;

there were 49 inches in November, 118 inches in December, and 120 inches in January. Precipitation was recorded on 24 days in December and 18 days in January. During December, all but one of the 18-ft movement stakes set in the cirque were completely buried. By the end of February the gauges registered 417 inches of new snow; the depth of new snow remaining on the Snowdome was 207 inches.

The liquid water equivalent of the snow falling on Blue Glacier is unusually high. Although falling snow does not generally exceed 10% liquid water equivalent, the snow that fell near the camp in December averaged 25%. An interesting related feature of the new snow during the season at Blue Glacier, samples of which are taken every 24 hours, is its persistently high density. (Generally this was found to be greater than 0.20 gm/cc. Even short-term samples, collected at intervals of one or two hours, have seldom fallen below a density of 0.15 gm/cc.) An important cause of these high densities appears to be the strong predominance of needle crystals (Type 4 of the International Snow Classification) in many snowfalls. The geometry of these crystals can produce snow of high density.

Winds: Wind velocities were generally high and progressively greater, with some fluctuation, throughout the August-through-January period. In September, winds up to 80 mph were recorded on two days. Although it was somewhat less windy in October, so-called damaging winds—winds with velocities greater than 50 mph—were frequent thereafter, occurring on almost half the days during December and January. Winds of more than 100 mph occurred on at least five days in November (some observations were lost because of anemometer failure) and on two days in January; on one occasion, gusts up to 130 mph were recorded.

Temperatures: In August, temperatures averaged 34.9°F. September and October were exceptionally warm months for the Blue Glacier region, averaging 42.3°F and 32.9°F, respectively. During December, temperatures were usually between 20°F and 30°F, with a low of 8°F for the latter half of 1957 occurring in that month.

Snow-Ice Budget: Owing to the abnormally warm weather through early fall, ablation continued during much of October; only six inches of new snow remained on the Snowdome at the end of the month, although 22 inches had fallen.

Although ice-budget studies have been sporadic because of the difficult and time-consuming logistic problems, preliminary results appear to show a slight deficit since last year. This is probably a consequence of light snowfall during the previous winter combined with high summer ablation that persisted longer than usual. Periods of heavy ablation resulted from warm summer storms with high winds. The last of the snow cover accumulated in the 1956–1957 winter season disappeared from the vicinity of the station in early September, whereas about 10 ft of snow had existed at the end of the previous year's ablation period. Snow accumulation in the upper cirque is also lighter than last year's; the maximum observed depth of 1956–1957 winter snow cover remaining in the upper cirque was 16–20 ft in mid-September. Photographic records of new snow-crystal types are obtained whenever a new snowfall occurs.

Movement: It was hoped that it would be possible to resurvey the movement stakes at 15-day intervals to establish the amount and rate of movement of the glacier. This schedule is difficult to keep during the mid-winter months, however, as the number of days on which activity on the glacier is possible is limited by heavy storms, often of blizzard intensity, and by the danger of avalanches along the route to the cirque.

Snow Temperature: A snow settlement gauge is in operation and temperature studies of snow and firn (old snow that has lasted

through at least one summer) are proceeding according to schedule. Significant results are being obtained. Winter chill, or sub-freezing temperatures, penetrated to a depth of about 10 ft in the firn by mid-February; the rate of penetration slowed progressively, and greatly, owing to the heavy insulating blanket of new snow.

A probe 50 cm long with thermocouples attached is used to obtain shallow temperatures in the snow and firn; for deeper temperatures, a 50-foot thermocouple cable was sunk into the glacier by hot point drilling. This cable extends to the isothermal layer.

Additional Studies: One new phase of investigation added after the program was under way is an extensive study of snow and ice albedo (percentage of light reflected by the surface), with emphasis on reflected solar radiation measurements made from a light aircraft. If possible, it will be carried out during the summer of 1958. Another, currently in progress when conditions are suitable, consists of time-lapse, photographic studies of cloud formation and development using a 16-mm movie camera. The Snowdome has proven to be an excellent "grandstand" for observing these cloud phenomena. In addition, microbarograph records are being collected for study of passages of fronts, and snow samples are obtained for oxygen isotope analysis at Caltech.

Solar radiation records have been obtained almost continuously but net and total radiation records have been irregular owing to frequent heavy formation of rime (opaque, granular, hard ice that forms on the upwind side of solid objects by freezing of supercooled cloud or fog droplets). This renders the radiometers inoperative for days at a time.

Caltech Studies

The work of the California Institute of Technology team is concerned only with the lower part of the ice stream, from the firn limit (lower limit of the accumulation area) to the terminus. It is hoped that these studies will yield basic information on the geometry and strain rates of Blue Glacier that will permit derivation of a basic flow law for valley glaciers.

The length of this segment of the glacier is 1.1 mi and the width is 0.6 mi. Like the University of Washington field party, the Caltech group received logistic support from the US Air Force and Coast Guard, and is aided materially by the National Park Service. The ski-wheel-equipped light aircraft is also used for resupply.

During the 1957 summer season the Caltech field party spent most of its time setting up experiments that will not yield maximum results until the 1958 season. However, some preliminary results have already been obtained.

Seismic Work: In the summer of 1957, thirty-five seismic stations were occupied on the ice tongue in the lower portion of Blue Glacier. Two of these stations were used solely for refraction and the remainder for reflection studies. A total of 144 records were made, of which two-thirds are expected to yield recognizable reflections.

At most stations the geophones were spread in both transverse and longitudinal orientations with respect to the glacier. Badly crevassed ice almost invariably gave poor results. At some stations no recognizable reflections could be obtained with transverse spreads, whereas excellent reflections were recorded with longitudinal spreads. This suggests that the floor beneath Blue Glacier may be very irregular on a small scale, thus complicating the reflection pattern.

The greatest ice thickness recorded during these seismic studies was about 920 ft, near the center line of the glacier a little below the firn limit. When carefully analyzed, the reflection records obtained along eight transverse profiles across the glacier should provide considerable information on the depth, slope, and configuration of

the subglacial rock floor. Data are meager, however, for portions of the glacier near the lateral margins, because of crevasses, thinness of the ice, and complications arising from reflections from the valley walls. Seismic refraction records indicate a wave velocity of 3650 m/sec within the ice.

Movement: To obtain movement profiles, eight transverse lines of stakes were set from just above the lower edge of the glacier to slightly above the firn limit. The stakes, of which 49 were used, were set at an average depth of about 10 ft in the ice. Their positions were determined by theodolite measurements with reference to a system of accurately located fixed points on bedrock and stable moraines along the sides of the glacier. Subsequent resurvey indicates the rate of flow of different parts of the glacier. Preliminary data suggest a maximum velocity along the flow centerline of about six inches per day. Ablation of the ice at these poles was close to 12 inches per week during August 1957, and was uniform over the entire glacier below the firn limit. The stakes will be resurveyed again in the summer of 1958. The resulting data are expected to give the actual flow vector and permit calculation of its various components. Stratigraphic studies of firn were made in two pits, one on the lower glacier and the other on the Snowdome.

Attempts were made to drive boreholes to the bottom at two separate but nearby locations on the glacier. Inclinometer surveys to measure deformation in pipes left in the holes permit construction of vertical profiles of glacier velocity. Neither borehole succeeded in reaching the bottom, but valuable data are expected.

Inclinometer surveys have been made at about 25-ft intervals in both boreholes. Such surveys will be repeated for several years, as long as the holes remain open and unobstructed. One hole, drilled where the ice is thought to be about 900 ft thick, reached a depth of 400 ft. The other, 500 ft up-glacier along the same flow line, reached a depth of 738 ft at a point where the glacier is judged to be 886 ft deep. Drilling became very slow in the deeper hole at about 690 ft, where it is surmised that a band or layer containing much rock debris was entered. Another attempt to drill to the bottom of the glacier will be made in the 1958 field season.

Ice fabrics and structure: Exploratory studies of ice fabrics, the patterns produced by the preferred orientations of ice crystals, were carried out on Blue Glacier during the 1957 field season. The studies had three objectives: a general survey of ice fabrics and their relationship to the easily visible folia tion pattern expressed by bubble layers in the glacier ice; a search for possible relationships between ice type and fabric type; study of the lateral persistence and significance of "multiple-maxima-type" fabrics, consisting of numerous clusters of crystals whose optic axes are oriented parallel to one another.

At all localities from which specimens were studied, a well-defined preferred crystal orientation was found. Coarse, recrystallized ice in Blue Glacier apparently has multiple-maxima fabrics, which have also been observed in other glaciers. Multiple-maxima fabrics appear to persist over distances of at least 15 ft laterally, retaining many of their main features. Fine, firn-like ice has fabrics with a well-defined crystal orientation parallel to the c-axes persisting over broader areas. The c-axes lie perpendicular to the plane of foliation.

Structures on the surface of lower Blue Glacier, such as foliation, crevasses, faults, and drag folds, proved to be unexpectedly well-developed and clearly displayed. Of particular interest is a double spoon-shaped structure which appears from beneath the firn and seems to extend to the terminus of the glacier. Detailed mapping and investigation of this and other aspects of Blue Glacier structure are planned by the Caltech group for the 1958 summer season.

Seismic Studies in the Andes

It has been the customary view of geologists that mountains and high plateaus are supported by a substructure of lighter crustal rocks extending downward into the heavier rocks of the earth's mantle, causing mountains to "float" in an isostatic balance, much as icebergs float. Mountains are themselves part of the 30- to 40-km-deep crust of the earth—which is made up of rocks such as lavas, metamorphosed sediments, and granites; these, through long epochs, are subjected to erosion, exposure and reburial, volcanic activity, and percolation of hot, mineralized solutions.

During investigations in the western United States in 1954, members of an expedition conducted by the Carnegie Institution of Washington found strong indications that another kind of substructure may also hold mountains up. A network of relatively narrow roots or veins of lighter crustal rock may project into the earth's mantle, the layer beneath the crust, to depths as great as 200 km. Since these diffuse roots are slightly less dense than the mantle rock, a crown of mountains—or an elevated plateau high above sea level—rises above them to equalize pressures, or maintain "floating equilibrium."

To test this idea elsewhere, the Carnegie Andes Expedition for the IGY during the summer of 1957 undertook investigations of the high regions of Peru, Bolivia, and northern Chile. In this work, they were aided by colleagues from the University of Chile and from San Marcos University in Peru. Their immediate aim was to attempt to determine the character of the roots of the Andes by measuring the waves from explosions used in the great open-pit copper mines of Peru and Chile.

(Compressional elastic waves, such as those generated in the earth by earthquakes or explosions, show a velocity of 5.6–6.1 km/sec in the lighter crustal rocks of the earth. Below the crust, an abrupt transition zone called the M-discontinuity (Mohorovičić discontinuity) is found in most places. Beneath this, in turn, are the heavier rocks of the earth's mantle, in which velocities range from 7.8 to 8.3 km/sec for compressional elastic waves.)

Members of the 1954 Carnegie field party in Arizona, New Mexico, and Utah had discovered that the thickness of the crust—as shown by strong reflections of compressional waves from the upper surface of the mantle—is about the same under the high Colorado Plateau as under the much lower plains and mountains of the eastern United States. This thickness of crustal material, 29 to 34 km, was also found under still higher Alaskan mountains on a 1955 Carnegie Expedition.

Two areas of the globe other than the Colorado Plateau region are characterized by a huge mountain bulk supporting an extensive elevated plateau—the Himalayas in Tibet and the Andes of southern Peru, western Bolivia, and northern Chile. The Andes, where thousands of cubic miles of rock rise to form a tremendous 12,000- to 16,000-ft plateau called the altiplano, were chosen as the site for a continuation of these studies.

In several of the Peruvian and Chilean copper mines single shots of 40 to 60 tons of dynamite are exploded almost every day. These explosions produce elastic waves, especially compressional waves, which pass through the crustal rocks and the higher-velocity rocks of the mantle below the M-discontinuity. It was hoped that observation of these waves, both those travelling along lines parallel to the mountains and those travelling across and beneath the mountains, would provide some clues to the character of the deep-lying structures that support these towering mountains (see Fig. 2).

The expedition, consisting of eight men and six trucks, left Washington in July 1957 and assembled in Lima, Peru, on August 14. During the next three months its members

made measurements and recordings at more than 200 carefully selected locations deep in the mountains of Peru, Bolivia, and Chile. Radio timing techniques were used for observing the waves from nearly 60 large explosions. Most of these explosions were at the Toquepala Mine of the Southern Peru Copper Corporation, about 60 miles northwest of Tacna; some were at the Chuquicamata Mine of the Chile Exploration Company, about 125 miles northeast of Antofagasta. Both of these mines are at elevations above 10,000 ft.

Detailed studies of the seismic records have not yet been completed, but the wave measurements indicate that the Andean structures are highly non-uniform. An unexpected difficulty was encountered: the 50-ton explosions were not large enough to permit outlining of the structures deep under the altiplano. Measurements of actual depths to the M-discontinuity by observing strong reflected waves were successful only in limited sectors along lines more or less parallel to the mountains. Suitable observations directly across the mountains were not obtained in spite of weeks of intensive effort.

The reflection waves passing under the altiplano were attenuated to an extreme degree, a situation never encountered in the work in North America. This extreme attenuation may have some connection with the volcanic structures in the Andes, probably indicating that the sharp initial wave pulse is converted to secondary waves at countless interfaces within the mountain structures. Many successive wave conversions then reduce the initial pulse to a long wave train of very low amplitude, which does not show on the instruments above the general unrest of the earth's surface.

By sustained and intensive search, instrument locations were found that were very quiet by comparison with those occupied previously in North America. Although in many places the instruments were capable of detecting vertical wave motions of less than ½ Ångstrom in amplitude (1 Å equals

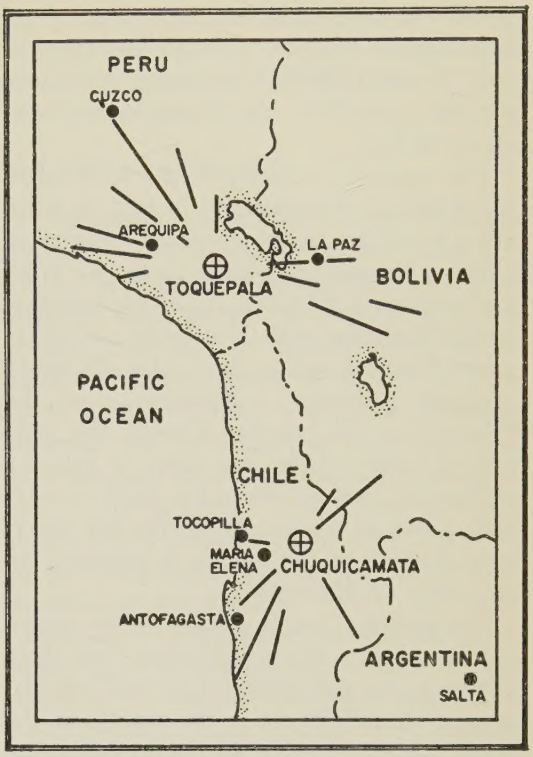

Fig. 2. *Regions in Peru, Chile, and Bolivia Investigated During Carnegie Institute Andes Expedition. Observations of Seismic waves from explosions in mines at Toquepala and Chuquicamata were made approximately along the radial lines.*

one hundred millionth of a centimeter), no waves were recorded in Bolivia, on the other side of the mountains at distances of 250–450 km from the explosion sites. The amplitude of a normal total reflection in this region would have been expected to reach as much as 600 Å. The reflections observed at comparable distances along the sides of the main bulk of the altiplano, roughly paralleling the mountains, reached amplitudes of 500–800 Å in both Peru and Chile, as might have been expected on the basis of the earlier work in the Rocky Mountains and Alaska.

In Peru, beneath regions with average elevations of 9,000–10,000 ft, the depth to what appears to be the top of the mantle was found to be about 34 km, approximately the same as under the Rocky Mountains in the United States and Alaska. However, in northern Chile, again along lines roughly

parallel to the mountains, in an area east of Antofagasta with an average elevation of only about 5,000 ft, the strong reflections showed a depth to the M-discontinuity of about 55 km.

The apparent velocity in the rock below the reflection discontinuity in each of these areas is similar to the expected velocity of about 8 km/sec for mantle rocks. As in all measurements of mantle velocities, however, non-uniformities in the overburden of 30 km or so of crustal rock in the Andes effectively prevents precision measurements of the velocity in the mantle. During the past several years there has been a growing realization that the idea of a single, world-wide value of wave velocity for the outermost portion of the mantle is probably an erroneous simplification.

The principal result of this seismic reconnaissance, then, is the indication that there appear to be non-uniformities and regional geographic differences in the mantle of the earth, just as there are in the crustal rocks. Under northern Chile, it appears that the lighter rocks of the crust project downward to nearly 55 km. This by itself is enough to float the mass of the Andes overhead. On the other hand, in southern Peru, the crustal rocks extend only to the normal depth of 34 km, and the towering Andes in that area are presumably held aloft by more diffuse roots projecting as much as 200 km into the mantle itself, or at least far below the levels where reflections of the explosion waves could have been observed.

Extensions of these observations of crust and mantle under the Andes may be made in the future by studies of local earthquake waves using a closely-spaced network of special seismographs. Further observations of explosion waves toward the coast are expected to be made during the IGY by the Geophysical Institutes of the University of Chile and of the San Marcos University in Peru using the Carnegie trucks and equipment, most of which were left in South America for this cooperative extension of IGY activity.

Rockoon Flights in the Atlantic, Pacific, and Antarctic Areas

This report is based upon material furnished by James A. Van Allen of the State University of Iowa.

From September 26 to November 9, 1957, thirty-six rockoons (balloon-launched rockets) were launched from the Navy icebreaker USS *Glacier*, as part of the US-IGY program. The first rockoon launching in this series was at 30°N in the Atlantic and the last was at 72°S in the Ross Sea adjacent to Antarctica. James A. Van Allen and Laurence J. Cahill, Jr., of the State University of Iowa (SUI) were in charge of the scientific portions of the program.

This work, together with earlier launchings in the Arctic in August 1957 (described in *Bulletin No. 5, November 1957*), constitutes a unified high-altitude investigation of cosmic-ray, auroral, and geomagnetic phenomena from 75°N to 72°S latitude.

The *Glacier* sailed from Boston on September 23, 1957, passing through the Panama Canal on September 30. It proceeded to the Line Islands area in the central Pacific, then sailed south, entering the Antarctic ice pack on October 31 at about 66°S, 178°W, and penetrating the pack to 72°05′S, 176°30′E.

Launchings were concentrated in the region of the Line Islands in the central Pacific, within the southern auroral zone in the south Pacific, and the Ross Sea. In addi-

tion, a series of flights was conducted along the ship's track, and two flights were made off the coast of New Zealand in a cooperative study with the low-frequency ionospheric station of Canterbury University College.

Arrangements for the rockoon-borne experiments were made with US Navy Task Force 43 by the IGY Inter-Service Coordinating Group. Through the courtesy of the Commander Task Force 43 and the Commanding Officer of the *Glacier*, substantial modifications of the sailing plan were made and extensive shipboard facilities and personnel assistance were provided.

Flight Summary

As in the earlier work in the Arctic, the Hawk rockoon vehicle was used (Fig. 3). The rocket was a modified Loki II solid-propellant unit with the experimental apparatus fitted to the forward end in a pointed cylinder, 3 or 3½ inches in diameter and about 38 inches in length. The payload (the weight of the instrument package) varied from 8 to 9.5 pounds. The rocket was suspended on a long load line beneath a 26,000-cubic-foot plastic balloon. It was fired by a barometric pressure switch when the balloon reached an approximate altitude of 23 km. The rockets reached altitudes of about 125 km. A tabulation of flights is given in Table 1.

All balloons performed satisfactorily, although two were damaged during inflation and were discarded. Of the 36 rocket-launching attempts, 20 can be considered normal flights, with summit altitudes ranging from 105–135 km. Seven rockets did not fire; two performed erratically; six were lost owing to equipment failure; and one was lost at launching, in a squall.

Objectives and Results

A major purpose of the rockoon program is measurement of total cosmic ray intensity over a wide range of geographic and geomagnetic latitudes during the present period of high solar activity. Special points of interest are (i) comparison of the intensity at upper atmosphere levels in high southern latitudes with intensity at high northern latitudes, and (ii) investigation of the location of the latitude "knee" (the geomagnetic latitude at which the number of incoming particles appears to fall off sharply) in the southern hemisphere.

Satisfactory cosmic ray intensity measurements up to an altitude of 23 km were obtained in a total of 15 flights distributed along the ship's track from 25°N to 72°S. On four flights (Nos. 52, 76, 84, and 85) satisfactory intensity data at upper atmosphere levels were obtained. These flights were made in many latitudes, but a variety of equipment failures caused a gap in the measurements in the vicinity of 30°S.

By January 1958, five sets of flight data had been read and reduced. They indicate that the total cosmic ray intensity at upper atmosphere levels in high southern latitudes is within 5% of that in high northern latitudes, and about 4.3 times as great as that near the equator. They also show that during the present period of high solar activity the

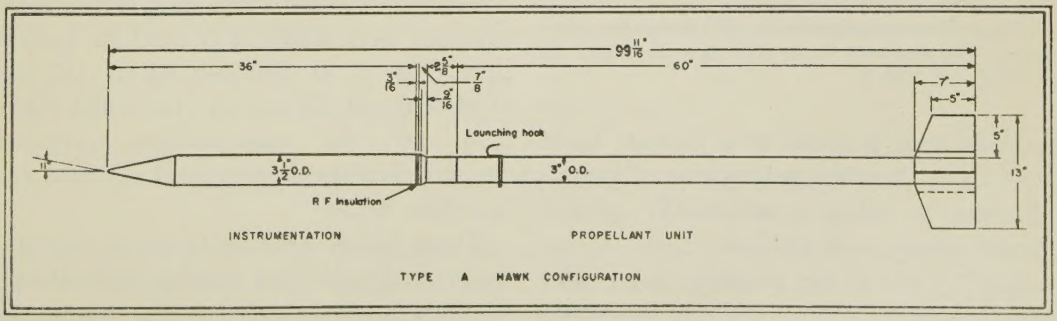

Fig. 3. Modified Loki II Rocket Used in Rockoon Experiments

Table 1. *Tabular Summary of Hawk Rockoon Flights*

Equatorial-Antarctic IGY Expedition, 23 September–10 November 1957

Date	Time (UT)	Geographic Position		Type of Instrumentation
26 Sept	1705	30°37′N	74°09′W	Test flight
27 Sept	1312	25°20′N	74°24′W	CR
4 Oct	1916	05°28′N	89°29′W	CR
13 Oct	1815	02°10′N	143°08′W	CR
14 Oct	2116	02°16′N	150°23′W	PPM
16 Oct	2002	07°07′N	156°38′W	PPM
17 Oct	0009	06°28′N	156°55′W	PPM
17 Oct	0218	06°11′N	157°01′W	PPM
17 Oct	2001	03°56′N	158°07′W	PPM
17 Oct	2344	03°23′N	158°41′W	PPM
18 Oct	0935	01°52′N	159°55′W	CR
18 Oct	1943	00°48′N	160°32′W	PPM
18 Oct	2343	00°02′N	160°52′W	PPM
19 Oct	1850	02°05′S	161°05′W	PPM
20 Oct	0106	02°31′S	161°25′W	PPM
20 Oct	0357	02°50′S	161°28′W	CR
20 Oct	2011	06°34′S	162°10′W	CR
22 Oct	2231	17°42′S	163°24′W	CR
26 Oct	1947	39°04′S	165°59′W	CR
27 Oct	0246	40°27′S	166°11′W	CR
29 Oct	0013	50°43′S	169°39′W	CRA
30 Oct	2140	60°05′S	176°06′W	CRA
31 Oct	0029	60°44′S	176°38′W	CRA
31 Oct	1951	65°03′S	177°51′W	PPM
1 Nov	0100	65°38′S	177°38′W	PPM
3 Nov	2008	70°14′S	175°42′E	PPM
3 Nov	2324	70°48′S	175°50′E	CRA
4 Nov	0141	71°10′S	176°08′E	PPM
4 Nov	0347	71°28′S	176°45′E	PPM
4 Nov	0716	71°58′S	175°40′E	CRA
4 Nov	1852	70°51′S	173°33′E	PPM
5 Nov	0125	69°32′S	173°38′E	CRA
5 Nov	1913	66°35′S	174°37′E	PPM
5 Nov	2159	66°09′S	174°41′E	PPM
8 Nov	2043	48°18′S	173°55′E	CRA
8 Nov	2315	48°01′S	173°50′E	CRA

Code: CR —Cosmic ray instrumentation
PPM—Proton precessional magnetometer
CRA—Cosmic ray and auroral instrumentation.

Note: The rockets fired in this series are numbered consecutively from IGY No. II 5.50 F to IGY No. II 5.85 F.

latitude knee is found at a latitude lower than 50°S. Cosmic ray intensity at various altitudes is being systematically plotted against geomagnetic latitude.

Another aim of the program was precise measurement of the intensity of the terrestrial magnetic field to altitudes over 120 km

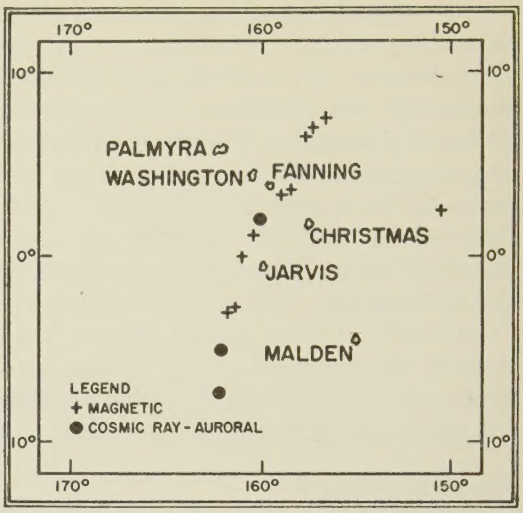

Fig. 4. *Line Islands Area, Showing Locations of Rockoon Flights.*

in the region of the equatorial electrojet. For these studies, a miniaturized proton precession magnetometer, designed at the State University of Iowa, was used. A detailed comparison of these data with simultaneous measurements made independently with variometers at the nearby IGY magnetic observatories on Palmyra, Fanning, and Jarvis Islands, in the Line Islands group, will be made. (These island observatories are operated by the Scripps Institution of Oceanography for the US Coast and Geodetic Survey and the Office of Naval Research.) Special interest was attached to the detection and measurement of electrical currents in the ionosphere by means of devices extending outward from the sides of the rocket. Such devices permit direct contact with the surrounding atmosphere.

Four satisfactory sets of data on magnetic intensity were obtained in the Line Islands area (Fig. 4) at altitudes up to 135 km (flights 54, 59, 62, and 63). On a fifth flight (No. 64), the magnetometer operated properly but the rocket's peak altitude was less than 70 km.

These flights were made on an approximate north-south line crossing the latitudes of the equatorial electrojet. The two sets of data which have so far been read indicate an

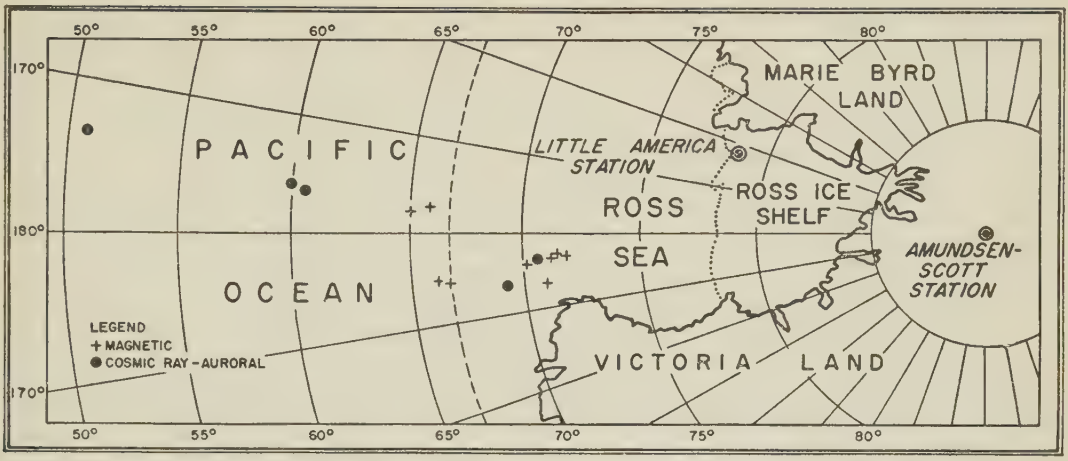

Fig. 5. *South Pacific and Ross Sea Areas, Showing Locations of Rockoon Flights.*

irregular, larger-than-normal decrease of 135 gammas in the total magnetic intensity, within the altitude range 97–121 km at 0° latitude. The absolute accuracy of each of a large number of measurements in this region is +5 gammas. Up- and down-leg data agree closely.

The data from flight 59, at 3°23′N, show a perceptible but markedly smaller discontinuity. The full reduction of all four sets of flight data obtained in the Line Islands area, when combined with the ground station measurements, are expected to yield illuminating information on the equatorial electrojet.

Several other experiments were conducted in the southern auroral zone. High-altitude measurements of the magnetic field were made for correlation with nearby Antarctic observations (Fig. 5). There were three successful magnetometer flights (Nos. 77, 82, and 83). Flight data have not yet been reduced. Investigations were made here of the physical nature, intensity, and latitude distribution of the "soft radiation" associated with auroras. Flight 76 (70°48′S, 175°50′E) was the only successful rocket flight of auroral instrumentation made in the zone. It encountered a high intensity of soft radiation resembling that studied extensively in the northern auroral zone during SUI rockoon expeditions from 1953 to 1957.

Precise absolute measurements of the intensity of the terrestrial magnetic field at sea level were taken at a number of new locations. Two new series of absolute values were obtained. The first series, in the Line Islands area, showed the current magnetic chart, No. 1703 of the US Hydrographic Office, to be correct within the limits of accuracy indicated. The second series of measurements, made in the Ross Sea, showed Chart No. 1703S, which was based on limited data, to be substantially in error in that region. The new values will be published shortly.

Variations in Cosmic-Ray Intensity

Observations of cosmic ray intensity at the earth's surface have long revealed many variations, both periodic and non-periodic. As noted in the report, "Thule Neutron Monitor Station," in *Bulletin No. 8, February 1958*, the intensity of the meson (heavy particle) component of cosmic radiation depends in a very complicated manner on the

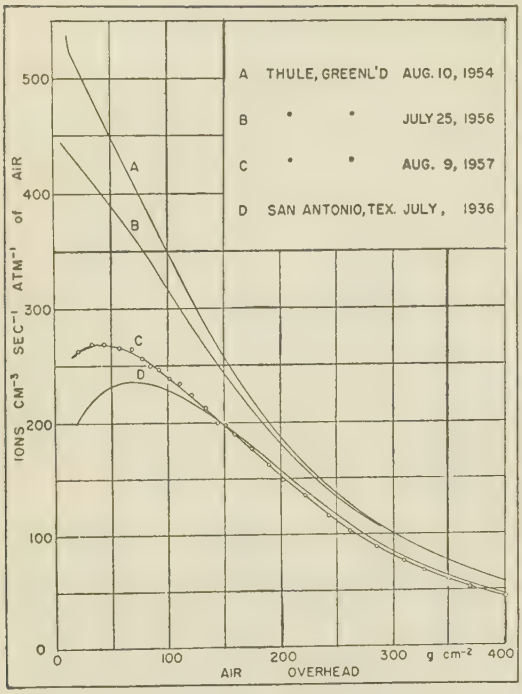

Fig. 6. *Cosmic-Ray Intensities in 1954 and 1956, Years of Low Solar Activity, Compared with Intensities in 1936 and 1957, When Solar Activity Was High.* (*Reprinted from* Physical Review.)

structure of the ever-changing atmosphere. A number of other intensity variations in both time and space are also observed. Some of these may give clues to the processes which produce and affect cosmic rays.

The largest of the observed variations in cosmic ray intensity are the rare increases associated with solar flares. At these times, neutron-monitor count rates may increase twenty-fold for a short period of time. Such flares have only been observed some half-dozen times.

Another non-periodic variation is the Forbush type of world-wide intensity decrease which occurs in association with some geomagnetic storms. In the Forbush-type decrease the cosmic ray intensity measured in ionization chambers may fall as much as 12% from the "normal" level. In neutron monitors the decrease may be as large as 2½ times this value, depending on the latitude of the station. Recovery to normal level may require days or weeks after a decrease occurs. These decreases occur much more frequently than the solar flare effects, but they do not occur in a periodic pattern. Nearly all such decreases occur during magnetic disturbances, although there are many cases of magnetic storms without accompanying decreases in cosmic ray intensity.

A number of periodic variations are also observed. Seasonal variations in the meson component are probably due entirely to atmospheric causes. The solar diurnal variations recorded by neutron monitors do not arise from atmospheric effects. A semidurnal variation is attributed to the fact that cosmic ray intensity is not the same in all directions.

During the very infrequent solar-flare increases, the variation in intensity may be as great as 25 times the level normally recorded. The decrease in intensity associated with geomagnetic storms may, as has been indicated, amount to as much as 30%. The solar diurnal variation has an amplitude of only 0.2%.

With the exception of the solar-flare increases, cosmic ray intensity variations at surface level are moderate. But investigations made prior to the IGY by H. V. Neher, of the California Institute of Technology, demonstrated that large changes do occur in the primary radiation arriving at the top of the atmosphere, especially in the north polar region. Over a period of years, Neher made observations near the north geomagnetic pole using ionization chambers carried by sounding balloons. His observations show that when the solar activity, as indicated by sunspot numbers, reaches a maximum in the eleven-year cycle the cosmic ray intensity decreases. This was also shown by results from the Carnegie Institution ionization chambers.

Near the north geomagnetic pole the flux of primary particles increased two-and-a-half times from the solar activity maximum of 1937 to the solar activity minimum of 1954. Most of this change was in protons at very low cosmic ray energies, below 10^9 electron volts.

This work has been continued in the IGY with balloon flights made during the summer of 1957 at Thule, Greenland. Figure 6 illustrates the large change that took place as solar activity increased during the cycle. Ionization due to cosmic rays at Thule during this period is reported by Neher and H. Anderson to be nearly 30% lower than during the solar maximum in 1937. They note that this is consistent with the higher level of solar activity during this cycle compared with the cycle of 20 years ago. In Figure 6, the rise of curve C above curve D at low pressures shows that more low-energy particles are present at high altitudes. Comparison of the results at Thule for the solar minimum of 1954 with those of August 1957 (near a maximum of activity) indicates that the total number of cosmic ray particles of all energies dropped by a factor of 4 in that period.

Observation of another variation during the IGY has been made with balloon-borne quadruple-coincidence counter trains launched at Swarthmore, Pennsylvania, under the supervision of M. A. Pomerantz, S. P. Agarwal, and V. R. Potnis, of the Bartol Research Foundation, for the purpose of detecting primary cosmic rays. When such flights were conducted during the period of general decrease of solar activity, 1949–1952, no changes in the primary intensity—as measured with counter trains containing 7.5 cm of interposed lead—were observed (with the exception of the rare increases associated with solar flares).

This is no longer true during the present period of high solar activity. Balloon flights (July–October 1957) have shown that the cosmic ray flux sometimes decreases by as much as 25% below the normal intensity of the earlier experiments. Within the limits of the apparatus, no changes in counting rate were detectable at altitudes below 60,000 feet, but at the highest altitudes attained the intensity varied between the earlier "normal" value and the minimum value.

From preliminary analysis of the data, a 27-day recurring variation has been observed. It has been followed through four cycles. Presumably, this effect is associated with a solar phenomenon which modulates the primary cosmic ray flux and is related to the 27-day solar rotation period. Surface level variations with similar dependence upon the 27-day solar cycle have been established in the past, but were of greatly reduced amplitude.

Second and Third US-IGY Satellites

1958 Beta

The second US-IGY satellite, 1958β, was launched from Cape Canaveral, Florida, at 7:16 am EST on March 17, 1958, under the direction of the Naval Research Laboratory.

Launching: The launching vehicle was a three-stage rocket, the third three-stage rocket fired in the Project Vanguard test program. The first and second stages were liquid-fueled rockets, the third stage a solid-propellant rocket. The first and second stages were stabilized and steered by altering the direction of thrust of the rocket motors. The third stage was stabilized by spinning the rocket about its longitudinal axis prior to ignition of the third-stage motor, thus integrating and cancelling out directional errors. The launching vehicle is approximately 72 feet long and 45 inches in diameter at its base. It is finless and has a gross take-off weight of 22,600 lbs.

Satellite Characteristics: The satellite, actually a test "payload," is an aluminum sphere, 6.4 inches in diameter and weighing about 3¼ lbs. It carries two radio transmitters and has six antennas (Fig. 7).

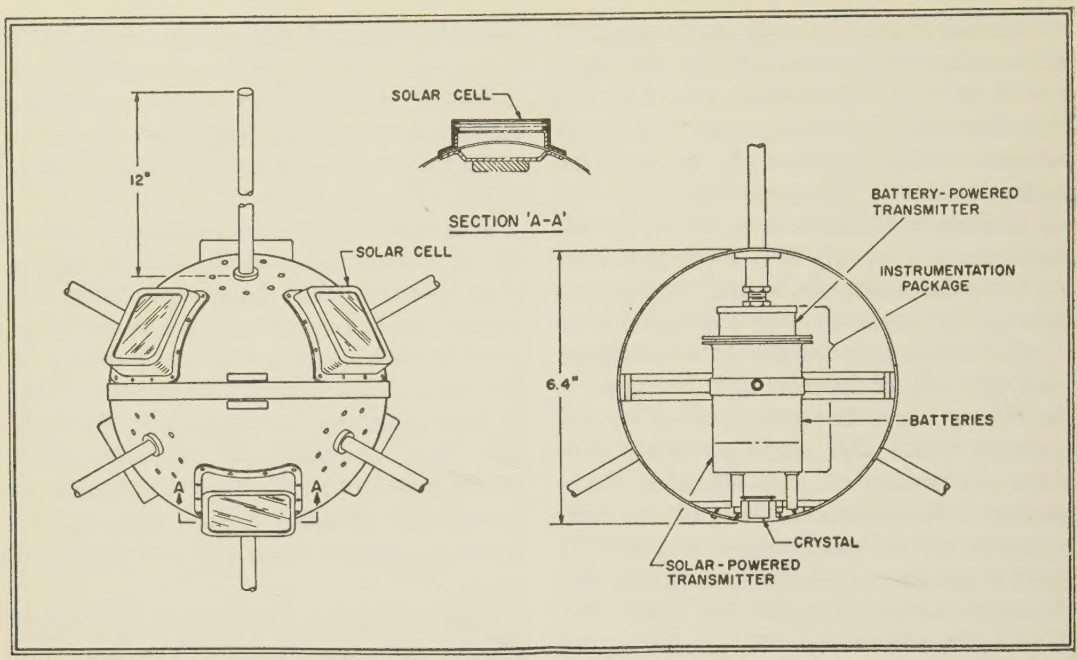

Fig. 7. Diagram of 1958β.

Instrumentation: Since the purpose of the test payload was to provide radio signals by which the rate of acceleration of the third stage could be determined and the efficiency of the separation mechanism checked, the test satellite carried no instrumentation other than the two radio transmitters. One transmitter, radiating 10 milliwatts at 108.00 megacycles, is powered by mercury batteries. This transmitter, which was expected to have a life of approximately two weeks, ceased operating on April 5th. The other, radiating 5 mw at 108.03 mc, is powered by solar batteries which have an indefinite life.

The frequency of each transmitter is controlled by a quartz crystal. Since changes in crystal temperature will cause changes in the frequency transmitted, temperatures at the crystal locations can be computed by measuring the changes in transmitter frequency. The crystal for the solar-powered transmitter is located just beneath the skin of the satellite; the crystal of the other transmitter is at the center of the satellite. Therefore, temperatures at these locations can be measured whenever the transmitters are in operation.

The solar batteries used were developed at the US Army Signal Engineering Laboratories at Fort Monmouth, N. J., under the direction of Hans K. Ziegler. They are a development of a solar battery first produced by Bell Telephone Laboratories in 1954.

Each battery consists of a series of 18 silicon cells, 1/400th of an inch thick; each cell contains two layers of silicon of differing electrical properties. When sunlight strikes a cell, electrons move from the positive layer (p-type) to the negative layer (n-type). The power thus made available to the 108.03 mc transmitter is approximately 40 mw.

Six solar batteries are spaced on the surface of the satellite so that at least one of the batteries will be in direct sunlight unless the satellite is in the earth's shadow. Because of the distance of the satellite from the earth, the satellite is expected to be in shadow only 15% of the time.

Orbit: The orbital elements for March 17 at 13 hrs 58 min 11 sec UT (the time of the first ascending node), as computed by the

Vanguard Control Center on March 18, were:

Period, 134.0 minutes; apogee, 2466 statute miles; perigee, 404 statute miles; inclination of the orbit, 34.1°; longitude of ascending node, 129.2°E; westward geographic motion of the node, 33.89° per day; latitude of perigee on descending branch, 26.1°N; eccentricity of orbit, 0.191; semimajor axis, 1.362.

Observations: Radio signals were received from the satellite on each pass until the battery-powered transmitter ceased operation. Since then, signals have been received only when the satellite is in sunlight.

The first sighting of 1958β was by a Moonwatch team at Alamogordo, New Mexico, on the morning of March 19.

1958 Gamma

The third US-IGY satellite, 1958γ, was launched from Cape Canaveral, Florida, at 12:38 pm EST, March 26, 1958, by a Jupiter-C rocket developed jointly by the US Army Ballistic Missile Agency and the California Institute of Technology Jet Propulsion Laboratory.

Satellite Characteristics: The satellite has essentially the same physical characteristics as 1958α (see *Bulletin No. 10, April 1958*), but does not carry a turnstile antenna with its four whip-like extensions. It weighs 31.00 pounds; this is 0.20 pounds heavier than 1958α.

Instrumentation: As in 1958α, the cosmic ray experiments carried in 1958γ were designed and installed by the Physics Department of the State University of Iowa (SUI) under the direction of James A. Van Allen. The micrometeorite experiments carried in both 1958α and 1958γ were designed and installed by the Geophysics Research Directorate of the Air Force Cambridge Research Center.

The instrumentation of 1958γ is slightly different from that in 1958α. The differences are: addition of a magnetic tape-recorder unit, designed by G. H. Ludwig of SUI, to record and store information on cosmic rays

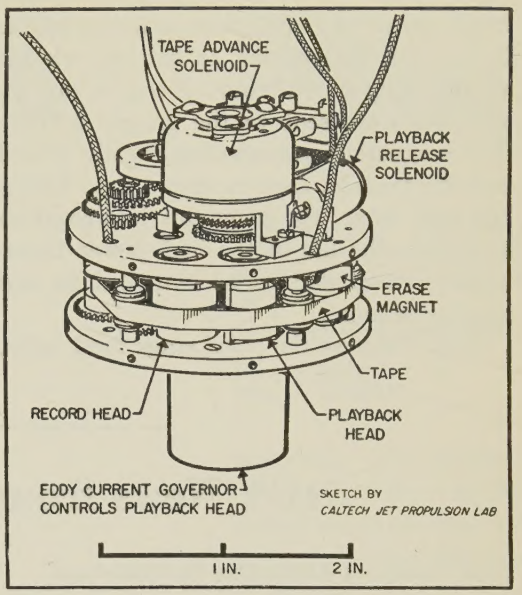

Fig. 8. *Magnetic Tape Recorder Used in 1958γ to Record Information and Transmit it to Ground Stations When Interrogated.*

gathered through an entire orbit; addition of a radio to receive interrogation signals from ground stations; omission of the microphone for recording of micrometeoritic impacts on the satellite shell; omission of the temperature probe in the nose cone; and use of a dipole antenna, formed by dividing the shell of the satellite itself, in place of the turnstile antenna.

1958γ carries two transmitters, identical to those in 1958α. The low-power transmitter, operating on 108.00 mc, transmits information continuously on skin temperature and internal temperature, micrometeorite counts as recorded by an erosion grid, and cosmic ray counts. The high-power transmitter, operating on 108.03 mc, transmits only when interrogated by a ground station, and sends only cosmic ray information recorded in the tape recorder memory unit (Fig. 8). It is interrogated each time it passes over the Minitrack network along the 75th meridian in North and South America. The signal from the ground station is picked up by a receiver; this starts the magnetic tape running over the playback

head and at the same time switches on the high-power transmitter. In five seconds the results of up to two hours of cosmic ray observations are sent to the ground station. The magnetic tape is automatically erased and the recorder reset to record data during the next orbit. By using this interrogation technique the life of the high-power transmitter is expected to be extended to two months or more.

Orbit: Because the third stage fired early, before it had reached proper alignment, the orbit of 1958γ is more elliptical than that of any of the IGY satellites fired earlier. The approximate orbit as of March 28 was: Period, 115.9 minutes; inclination of orbit to the equator, 33.8°; perigee, 116.9 miles; and apogee, 1740.8 miles. This somewhat eccentric orbit is providing a scientific bonus for it gives a sweeping profile of cosmic ray information from relatively low to quite high altitudes.

IGY News from Other Countries

New Zealand Antarctic Symposium

Scientists of seven nations met in Wellington, New Zealand, February 18–22, 1958, at the invitation of the New Zealand National Committee for the IGY, to take part in an informal discussion of IGY work accomplished in the Antarctic during the preceding year. Nations represented in addition to New Zealand were Australia, France, Great Britain, South Africa, the USA, and the USSR. Two types of meetings were held: those of general interest at which informal papers were presented and discussed, and round-table discussions among delegates concerned with a particular discipline.

A list of symposium discussions, together with the chairmen of each, follows: Special Investigations in Glaciology, J. L. Zumberge, US; The Topography of the Sub-Glacial Continent, Bertrand Imbert, France; Geomagnetism, R. L. Viets, US; Logistic Support Problems in the Antarctic, M. A. F. Barnett, NZ; Meteorology, V. I. Rastorguev, USSR; Seismology, T. Hatherton, NZ; Biology, Botany, and Zoology, R. W. Balham, NZ; Oceanography, U. V. Cassie, NZ; Aurora, F. Jacka, Australia; Geology, R. W. Willett, NZ; Radiation and Micrometeorology, Herfried Hoinkes, US; and Future Research in the Antarctic, G. de Q. Robin, Great Britain.

Most of the delegates had just returned from the Antarctic and had not had the opportunity to prepare formal papers. The symposium permitted exchange of field results and discussion of items of interest affecting future work without the need to wait for publication of papers.

Participants in the symposium are now preparing papers covering the subjects discussed. These papers will be published by the New Zealand National Committee for the IGY in the near future.

Preprinted from *Transactions, American Geophysical Union*, Vol. 39, No. 3, June 1958

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